THE STRUCTURE OF THE SIDEREAL UNIVERSE.

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As a result of new discoveries in the sciences related to Astronomy, such as Mathematics or Physics, or of the construction of various instruments of greater observing power, different branches of Astronomy have at different times engaged the attention of astronomers. During the last decade, interest has been centred in the problems connected with the structure and constitution of the sidereal universe, *i.e.*, in the physical properties of the fixed stars, their evolution, and their distribution in space.

The important and unexpected results recently brought forward in this connection are due to the successful accomplishment of the most difficult task confronting astronomers for more than half a century—I mean the measurement of the distances of the fixed stars. In the case of a star relatively near the earth, the distance may be determined by what is known as the trigonometric method. When the Sun is about 90° away from the star in the sky, the position of the star, as compared with a number of very distant faint stars surrounding it, is accurately measured. After six months, when the earth is at the opposite side of its orbit, the observation is repeated, and it is found that the star has apparently shifted slightly among the distant faint stars. From the amount of this shift, termed the *parallax*, the distance of the star may be deduced. Stellar distance is too great to be conveniently measured in miles, and hence the astronomer uses as a unit the "light year," or the distance which light would travel in one year. (One light year is equal to 5,870,000,000,000 miles.)

For most stars the parallax is exceedingly small and difficult to measure; it is like observing a shift of ½ inch at a distance of 20 miles. It is only during the last 15 years, with the aid of the largest modern telescopes and with the use of photography, that considerable progress has been made in these delicate measures. Six of the larger American observatories, together with the Greenwich Observatory, devote a great part of their time to this problem. At the present moment we have reliable measures of the distances of about 1,000 stars, and their number is rapidly increasing. Unfortunately the stars of the southern constellations cannot be reached by these observatories, and only for very few southern stars are the distances known. This is a serious handicap in studies on the structure of the sidereal universe, and astronomers are anxious that some observatory situated in the Southern Hemisphere be equipped with a large refractor and take up this line of work. Australia with its excellent observing conditions would have here an opportunity to make a very valuable contribution toward the advancement of human knowledge.

The method for measuring stellar distances outlined above gives reliable results only for the nearer stars, up to a distance of about 100 light years; for more distant objects the shift produced by the annual motion of the Earth around the Sun becomes too small to be measured with any degree of certainty. For penetrating farther into space we have to resort to more indirect methods. Before we enter on these, however, let us see what information about the constitution and the physical properties of the stars we obtain from the distance measures of those stars that are nearer than 100 light years. The stars, like the Sun, are big gaseous masses rendered highly luminous by their enormous temperatures (3,000° to 20,000°). There is no essential distinction between the Sun and a star; the Sun is just one among the many million stars of which the sidereal universe is composed; it is that peculiar star in whose planetary system we are living. To the astronomer it seems not only possible, but even probable, that other stars also have their planetary systems. The stars appear so much fainter to us than the Sun simply because of their incomparably greater distance. But even the stars among themselves appear very different in brightness, and we naturally inquire what factors produce this inequality in the apparent brightness. Comparing a bright star with a faint one, we may find that they actually send out the same amount of light, but that one of them appears fainter because it is farther away from us. On the other hand, we may find a pair of stars of dissimilar appearance which are at the same distance from us; in this case the two stars must be different in their actual luminosity. Popularly speaking, we may say that one of them has a higher candle power, and that the two stars appear to us like an arc lamp and a candle light seen at the same distance. We can observe directly only the apparent brightness of a star, which depends as we have seen, not only on its distance, but also as on its real luminosity; but if its distance is known, we can easily calculate the luminosity. One of the most important results in the measurement of stellar distance is that it gives us information about the luminosities of the nearer stars. In this way we find that the stars cover an enormous range of luminosity, some being over a million times as luminous as others, even if seen at the same distance.

In order to understand this unexpected result, we have to study the constitution of the stars more closely, and to take into account the observations obtained by means of the spectroscope. The starlight that reaches our instruments is a mixture of vibrations of different duration. The human eye roughly classifies these different vibrations as colours. When the light of a star passes through a prism of glass, the vibrations of different duration are separated, the light is spread into a band of colours which we call the spectrum, and this spectrum allows a careful analysis of the starlight. The colour band of a star is generally interrupted by numerous narrow dark lines. These so-called "spectral lines," representing isolated vibrations, are characteristic of the chemical elements of which the source of light is composed, or of the material through which the light is passing. An extensive spectroscopic study of about 200,000 stars has just been completed at the Harvard Observatory. This great piece of work is giving evidence of two important facts, first that the stars are composed of the same chemical elements which we know on the Earth, for only very few spectral lines cannot be identified and may be due to unknown elements, and secondly, that although the stellar spectra do not all show the same appearance, yet they can all be classified according to a few characteristic types. These spectral types with intermediate gradations form a continuous series. They seem to represent different stages in the evolution of the stars. While each star during its life history passes through approximately the same stages of evolution, the stars which we observe are not equally advanced in their development: some are "younger," others "older." Accompanying a change in the spectral type there is also a change in the colour of the star from bluish-white to white, yellow, orange and red.

Experiments in the physical laboratory have shown that a body is the more luminous the higher its temperature, and that at the same time the colour of the total light emission changes slightly from the red towards the blue. Therefore our spectral types represent different degrees of temperature, ranging from about 3,000° for the red stars to about 20,000° for the bluish-white stars. We should now naturally inquire if the large range in the luminosities of the stars is not in some way related to the temperatures and to the spectral types. Such an investigation made for the stars of known distance led Hetzsprung and Russell to the surprising result that the luminosities of the stars are indeed closely related to their spectral types, but that we have to divide the stars into two classes, viz., "*giant*" and "*dwarf*" stars. The high luminosity of the giant stars is about the same for all spectral types and temperatures, while the luminosity of the dwarf stars is very low for the red stars of relatively low temperature, but increases rapidly for the higher temperatures. The two classes of stars join each other in the bluish-white stars of high temperature, but are widely separated in the red stars of low temperature.

Let us compare for example a red giant star like *Antares* with a red dwarf star like that discovered a few years ago by Barnard through its rapid motion, and generally known under the name of Barnard's star. *Antares* is of first magnitude, Barnard's star appears 2,500 times fainter; but from parallax measures we find that it is also 40 times nearer to us than *Antares*. In reality, therefore, it must be four million times less luminous than *Antares*. What is the cause of this enormous difference of luminosity between the two stars that show about the same type of spectrum, and should be at nearly the same temperature? There remains only one explanation—a giant star like *Antares* must have a much larger surface, diameter, and volume than a dwarf star such as Barnard's star. This conclusion has recently found a brilliant confirmation, when the astronomers of the Mount Wilson Observatory in Southern California actually succeeded in measuring the diameter of *Antares* with a new instrument (the interferometer), and found it to be about 300 times as large as that of the Sun.

We should expect a giant star having so large a volume to be in proportion more heavy and massive. This, however, is decidedly contradicted by our information about the masses of the stars, meagre though it is. It is only possible to determine the individual masses of stars in cases of double stars, where two stars are close enough to each other to produce a sensible gravitational attraction, causing them to follow an orbital motion around their common centre of gravity. For a limited number of such binary stars the data necessary to calculate the masses are known, but all the results so obtained indicate that the masses of the stars vary only within a small range. We are thus led to the conclusion that giant and dwarf stars both contain a similar amount of matter; in a dwarf star this matter is concentrated in a small sphere, while in a giant star it is very tenuously distributed throughout an enormous volume. The density of matter prevailing on the average in a red giant star like *Antares* is low beyond imagination; it is rather less than one thousandth of the density of our atmosphere at sea level, and is only comparable with the density in a vacuum tube with less than 1 mm. mercury pressure.

As to the evolution of a star, it had been supposed until about 10 years ago, that a star during its lifetime passed once through the series of spectral types as the temperature decreased. The discovery of the giant and dwarf division among the stars introduced an unexpected complication, and led to a modification of this hypothesis. A star, according to this new theory of evolution, starts its life history, as far back as we can follow it, as a red giant star of relatively low temperature with an enormous volume and an exceedingly tenuous distribution of matter. In the stage of the red giant stars our Sun must have occupied a sphere extending beyond the present orbit of the planet *Mars*. Gravitation and radiation produce a gradual contraction, thus diminishing the volume and increasing the density and the temperature of the star. The giant star is passing through the different spectral types in the direction of higher temperatures until it reaches the stage of the white or bluish-white stars, where a turning point is reached. On account of the higher density the contraction is slowing down. The thermal energy gained by this contraction is no longer in excess of, nor even equal to the heat lost by radiation (increased by the high temperature). The star is beginning to cool, it has become a dwarf star and is again passing through the different spectral types, but this time in the direction of diminishing temperature. During its stages as a giant the star is nearly constant in luminosity, as the effect of smaller surface is about balanced by the increasing intensity of radiation per surface unit due to the higher temperature. As a dwarf, the star is very rapidly decreasing in luminosity; diminishing surface and decreasing intensity of radiation are both working together to reduce the amount of light sent out by the star. This continues until the star becomes too faint to be observed with our telescopes. Thus, if we classify all stars according to their volume (or density) instead of temperature, giant and dwarf stars from the two ends of one continuous series of increasing density passing twice through the series of observed spectral types.

It is interesting to note that the most recent researches in stellar evolution have led us to a theory that is entirely in harmony with the fundamental ideas of Laplace's Nebular Hypothesis set up over a century ago. Laplace tried to explain the formation of our planetary system by a gradual contraction of the Sun from a big nebulous body of low density (comparable to a red giant star) to its present size.

While the measures of the parallaxes of the nearer stars form the basis on which the theory of the giant and dwarf stars is built, this theory, once established, can now be applied to gain information about the distances of more remote celestial objects. If the spectral type of a star is observed, and if it is possible to decide whether the star is a giant or a dwarf, then our theory will give us immediately its luminosity, *i.e.*, its brightness if seen from the distance unit (33 light years). Measures of the apparent brightness of the star will tell us how much fainter it appears to us and how many distance units it must be away.

The most difficult part of this method is to separate the giant and dwarf stars. Dr. Adams at the Mount Wilson Observatory has found that a giant and a dwarf star of the same general spectral type differ in their spectra just by the intensity of a few lines. Careful observations of these spectral lines make it possible, if the star is not too faint for its spectrum to be photographed on a suitable scale, to determine directly its luminosity and to derive from its apparent brightness the distance (spectroscopic parallax).

The method of determining stellar distances from the spectrum and the apparent brightness is not only applicable to individual stars (even very faint ones, if the colour is used instead of the spectrum), but it has also given valuable information about the distances of star clusters and nebulæ (if stars are involved in these). Take for example the star cluster of the *Pleiades*. Most of the brighter stars in this group show motion in the same direction with equal speed, and they form a well defined system with common origin. Seen from the Earth this system appears projected on the celestial sphere together with many other stars, some of them nearer, most of them more remote than the *Pleiades*. By means of their common motion, however, it is possible to pick out the stars which are physical members of the *Pleiades* system from those which simply form the "background." Among these *Pleiades* members, for example, we find a star of 10th magnitude to be a dwarf star showing the same spectral type as our Sun. Hence we conclude that it has the same constitution and luminosity as the Sun. Having then measured how much fainter the star appears to us than the Sun, we can calculate how much farther it is away from us. Another *Pleiades* star of magnitude 7.5 resembles in its spectrum the near bright star *Sirius*, of which the parallax has been measured. A comparison of the apparent brightness of the *Pleiades* star with that of *Sirius* gives again a determination of the distance of the *Pleiades*. From a number of such comparisons the *Pleiades* group is found to be situated at a distance of 327 light years. Most of the other star clusters of the Milky Way are still more remote, and for some of the densely crowded globular clusters values as large as 100,000 light years are indicated by this method.

Other lines of research of a more statistical nature have also contributed largely to the knowledge of the structure of our stellar universe. I shall mention only the method of counting the numbers of stars that exceed different limits of brightness, and the study of the motions of the stars, which on the average must appear smaller the farther they are away. From all results bearing on this subject we come to the conclusion that the stars seen or reached with the telescope form a limited system, and that the Sun is situated not very far from its centre. This system, having approximately the shape of a flat lens, contains over a thousand million stars, and the Milky Way, or Galaxy, is an essential feature of it. It is for this reason that we call it the Galactic System. The plane of the lens coincides with the plane of the Milky Way, and the reason we find so many faint stars in the clouds of the Milky Way is that in this direction our system extends much farther, *i.e.*, we look through a greater depth. In other directions the limit of the system is nearer to us, and we find the fainter stars less numerous.

There is still considerable uncertainty about the dimensions of the Galactic System—estimates of its diameter ranging from 30,000 to 300,000 light years. Star clusters and nebulæ seem to belong to this system, especially to the more distant parts of the Milky Way. There is only one class of objects, the spiral nebulæ, which many astronomers believe to lie outside the Galactic System. Their spectrum resembles that of star light and suggests that these objects are composed of stars; that they are island universes similar to our own stellar universe, but situated at distances of millions of light years. It should however be mentioned that this view cannot yet be considered to be well established, and that much controversy on this point is going on at the present time.

Knowledge of stellar distances is one of the most important requirements for the understanding of the structure of the sidereal universe. Remarkable as is the progress made during the last decade in establishing our knowledge of these distances on a more accurate and reliable basis, much work still remains to be done in applying the methods recently developed to a larger number of and to more remote celestial bodies.